ACID – BASE DISORDERS

Dr Faraz Azim Niaz

- What is Acid-base balance ?

  - Acid-base balance is defined by the concentration of hydrogen ions. [H^+]

  - In order to achieve homeostasis, there must be a balance between the intake or production of hydrogen ions and the net removal of hydrogen ions from the body.

PRODUCTION = REMOVAL

- Acids:

  - Ionize in solution

  - Produce H^+ ions

  - The more H^+ ions produced the stronger the acid

  - Acids are <u>proton (H+) donors</u>

  - Two types of acids are formed by metabolic processes

    1. <u>Volatile acids</u>: liquid $\rightarrow$ Gas. CO_2 eliminated by lungs.

       $$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3$$

    2. <u>Non-volatile or fixed acids:</u> are eliminated by the kidneys

       SO_4,PO_4, lactic acid, ketoacids

NB

- The non-volatile portion is trivial when compared to the volatile CO_2 ; 50-100 meq/day.
- Under normal physiologic conditions, the body produces large amounts of acids as they are the end products of many metabolic processes.

- Bases:

- Ionize in solution

- Produce OH^- ions

- The more OH^- ions produced the stronger the base

- Bases are <u>proton (H^+) acceptors</u>, eg: HCO_3^- (bicarbonate)

ACID		BASE
H_2CO_3	$\longleftrightarrow$	$H^+ + HCO_3^-$
HCl	$\longleftrightarrow$	$H^+ + Cl^-$
NH_4^+	$\longleftrightarrow$	$H^+ + NH_3$
$H_2PO_4^-$	$\longleftrightarrow$	$H^+ + HPO_4^{2-}$

- How is Acid-Base balance measured?

  - Hydrogen ion concentration is expressed on a logarithm scale using pH units (part/percentage hydrogen). 7.0 being neutral

  - Body systems carefully control pH of the body within the range of 7.35 - 7.45

- pH:

  - What is pH ?

  - P French word- Pvissance (power); Meaning power of hydrogen

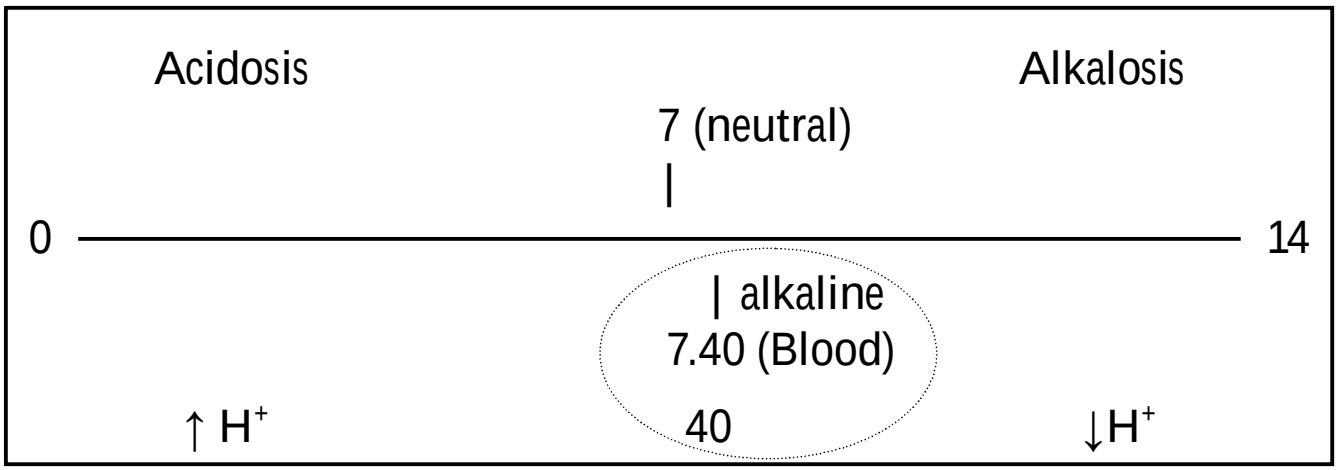
  - Definition: -ve log of [H+] conc., i.e.minus no. to which 10 must be raised to get that no.

pH

pH is the negative logarithm of the hydrogen ion concentration

Or the power of the H+ ion

- pH Scale:



- A low pH corresponds to a high hydrogen ion conc
- The term "Acidosis" refers to the **addition** of excess H+, body has a pH < 7.35

- A high pH corresponds to a low hydrogen ion conc
- The term "Alkalosis" refers to excess **removal** of H+, body has a pH >7.45

- How the Body defends against fluctuations in pH?
  - **Three Systems :**
    1- Buffers in the blood
    2- Respiration through the lungs
    3- Excretion by the kidneys

- pH change Regulation
  - The body constantly produces acids through metabolism
  - These acids must be constantly eliminated from the body
  - **Buffers**
    - » Chemical substance that prevents large changes in pH
  - **Ventilation**
    - » Can handle ~75% of most pH disturbances
  - **Renal regulation of H^+ & HCO_3^-**
    - » slow but very effective

- The Importance of the Body's Buffering Systems
  - Can be quickly realized if one considers the low conc of H^+ in the body fluids and the large amounts of acids produced by the body /day

    eg: 80 mEq of H is either ingested or produced each day by metabolism.
  - Whereas the H^+ conc of the body fluids normally is only about . 0004meq/L

- Buffers
  - Limit extreme changes in the H+ and the OH+ concentration

    2 types :

    1- Intracellular

    2- Extra-cellular(blood)- first line of defence

- Intra-cellular Buffers:

- Proteins
- Polypeptides

- Major Buffers (blood):

- Bicarbonate (50% of buffers)
- Hemoglobin (35% of buffers)
- Plasma proteins (6% of buffers)

- **Bicarbonate : Carbonic acid :-**

- Normal ratio of bicarbonate (HCO_3^-) to carbonic acid (H_2CO_3)= 20 : 1
- Addition of H^+ drives the equation to the right with increased CO_2

- **Respiration through the lungs:**

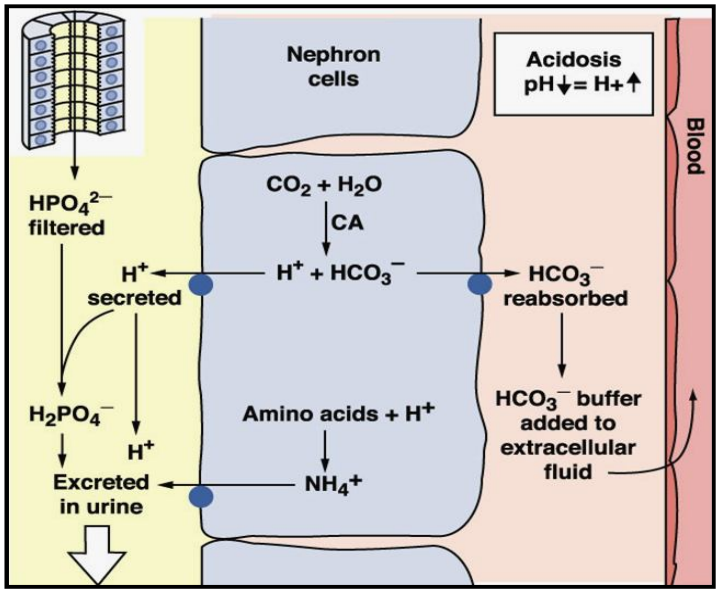
- CO_2 formed during cellular metabolism forms carbonic acid in the blood ↓ the pH
- When pH drops respiration rate ↑ , this hyperventilation increases the amount of CO_2 exhaled , lowering the carbonic acid conc & restoring homeostasis.

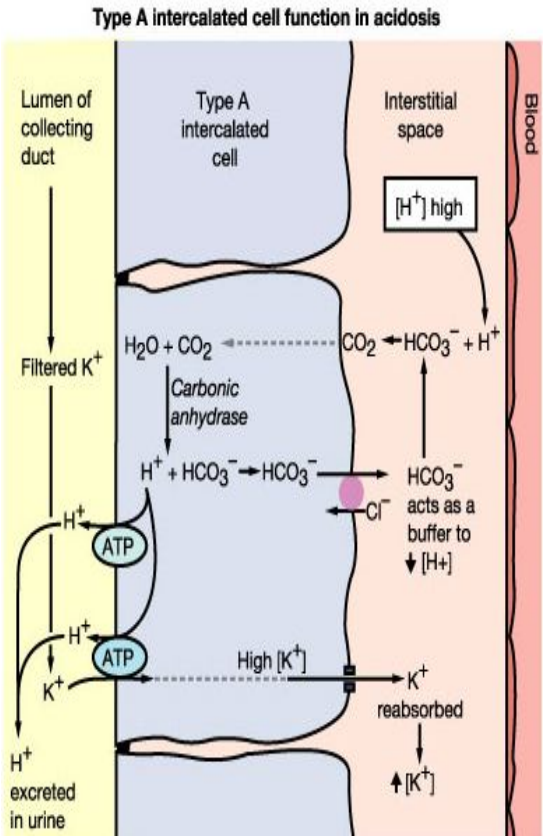
- **Excretion by the Kidneys:**

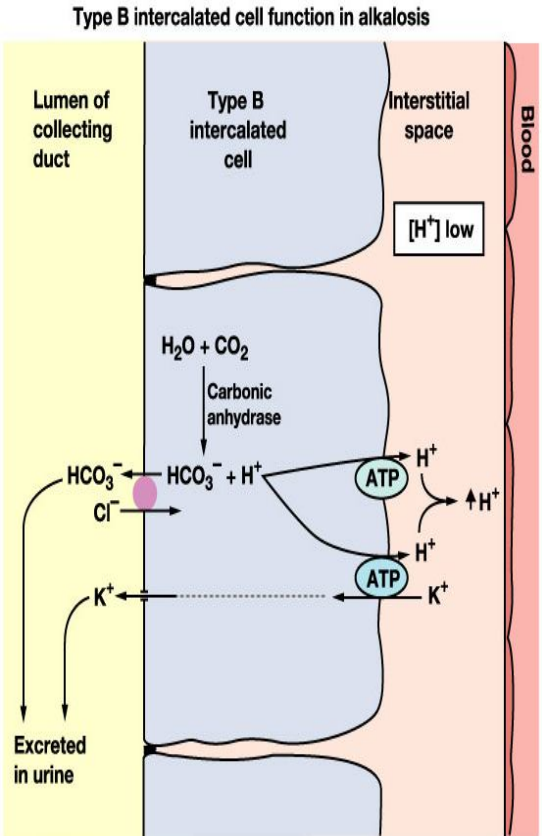
- The kidneys play the primary role in maintaining long term control of Acid-Base balance
- The kidney does this by selecting which ions to retain and which to excrete
- The kidneys adjust the body's Acid-Base balance

- Renal Buffer Effects
  - Excretes hydrogen ions
  - Produces and reabsorbs bicarbonate

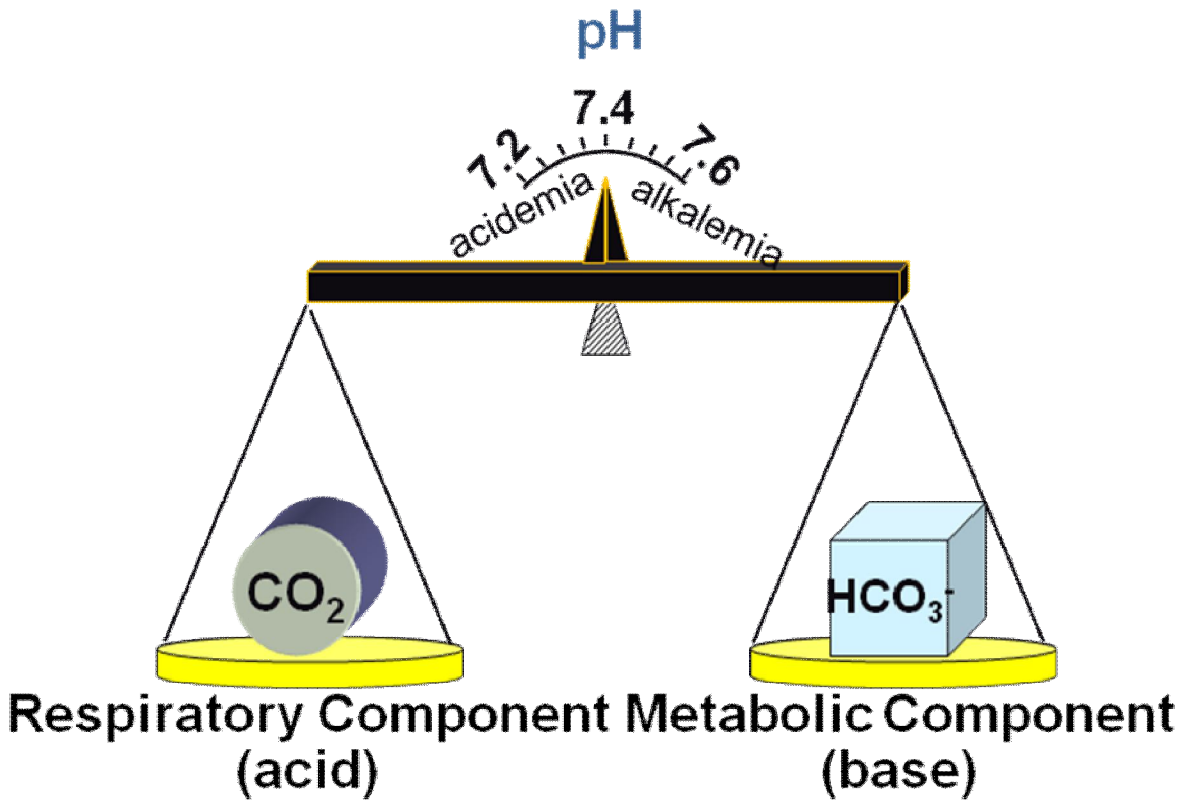
- Renal Tubule Cells
  - $H_2O + CO_2 \rightarrow H_2CO_3$
  - H_2CO_3 ionizes to H^+ & HCO_3
  - H^+ excreted in exchange for Na^+
  - $NaHCO_3$ reabsorbed and H^+ combines with NH_3 to form NH_4 which is excreted







Now, Please take A DEEP BREATH & Relax
Things start to be complicated!



There are 4 Types of Acid-base Imbalances:

- Respiratory Alkalosis
- Respiratory Acidosis
- Metabolic Alkalosis
- Metabolic Acidosis

- HENDERSON HASSELBALCH:

$$pH \propto \frac{HCO3}{PCO2}$$

- pH inversely proportional to PCO_2
- pH directly proportional to HCO_3^-

Respiratory acidosis $pH \downarrow \propto \frac{HCO3 \uparrow *}{PCO2 \uparrow}$	Respiratory alkalosis $pH \uparrow \propto \frac{HCO3 \downarrow *}{PCO2 \downarrow}$
Metabolic acidosis $pH \downarrow \propto \frac{HCO3 \downarrow}{PCO2 \downarrow *}$	Metabolic alkalosis $pH \uparrow \propto \frac{HCO3 \uparrow}{PCO2 \uparrow *}$

* - compensation process

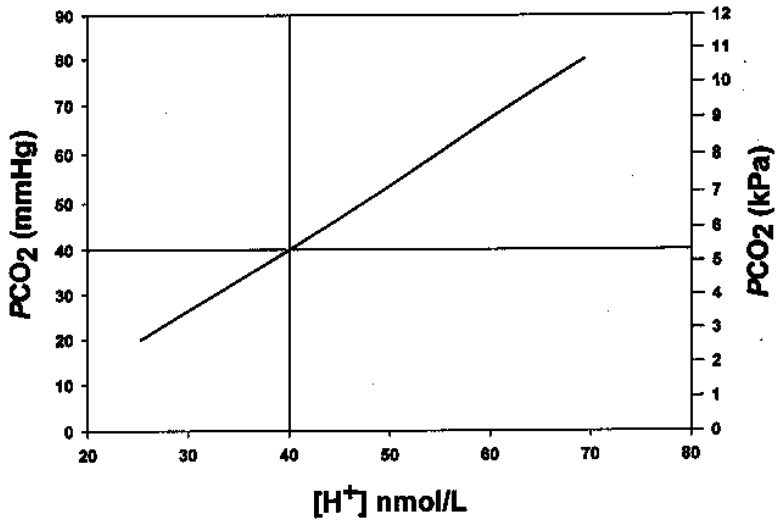
- UNDERSTANDING POOR!
  - Few understand that:
    - Identical **numerical** pH changes mean a **different order** of $[H^+]$ change:
      - pH 7.4 to 7.1 **doubles** [H+] (**40 to 80**)
      - pH 7.4 to 7.7 **halves** [H+] (**40 to 20**)

- WHY POOR UNDERSTANDING?
  - pH – reciprocal log scale
  - Calculator use: students have little understanding of logs
    - OK : $10^3 \times 10^4 = 10^7$
    - Not OK: fractional logs $10^{-7.4}$
      - despite higher school mathematics

RELATIONSHIP

pH	[H+] nmol/L
7.7	20
7.5	31
7.4	**40**
7.3	50
7.1	80
7.0	100
6.8	160

RELATIONSHIP BETWEEN $[H^+]$ AND PCO_2



- Physiological Response to increase in H^+ acid load
  - Buffer
  - Compensation
  - Correction

- COMPENSATION PRINCIPLES
  - Compensation - **partial**

    Except for mild respiratory acidosis/alkalosis
  - No **over**-compensation
  - **If $[H^+]$ normal in acid base abnormality:**
    - compensated resp acidosis/alkalosis
    - mixed primary disorders
  - **Mixed primary disorders :**
    - usually not balanced

- Clinical Manifestations due to altered pH & pCO_2:

↓pH <7.20 Depressed sensorium Depressed myocardium	**↑pCO2 >50** Headaches Papilloedema asterixes
↑pH >7.55 Seizures-Vent. arrythmias	**↓pCO2 <30** Coronary spasm ECG-ST elevation

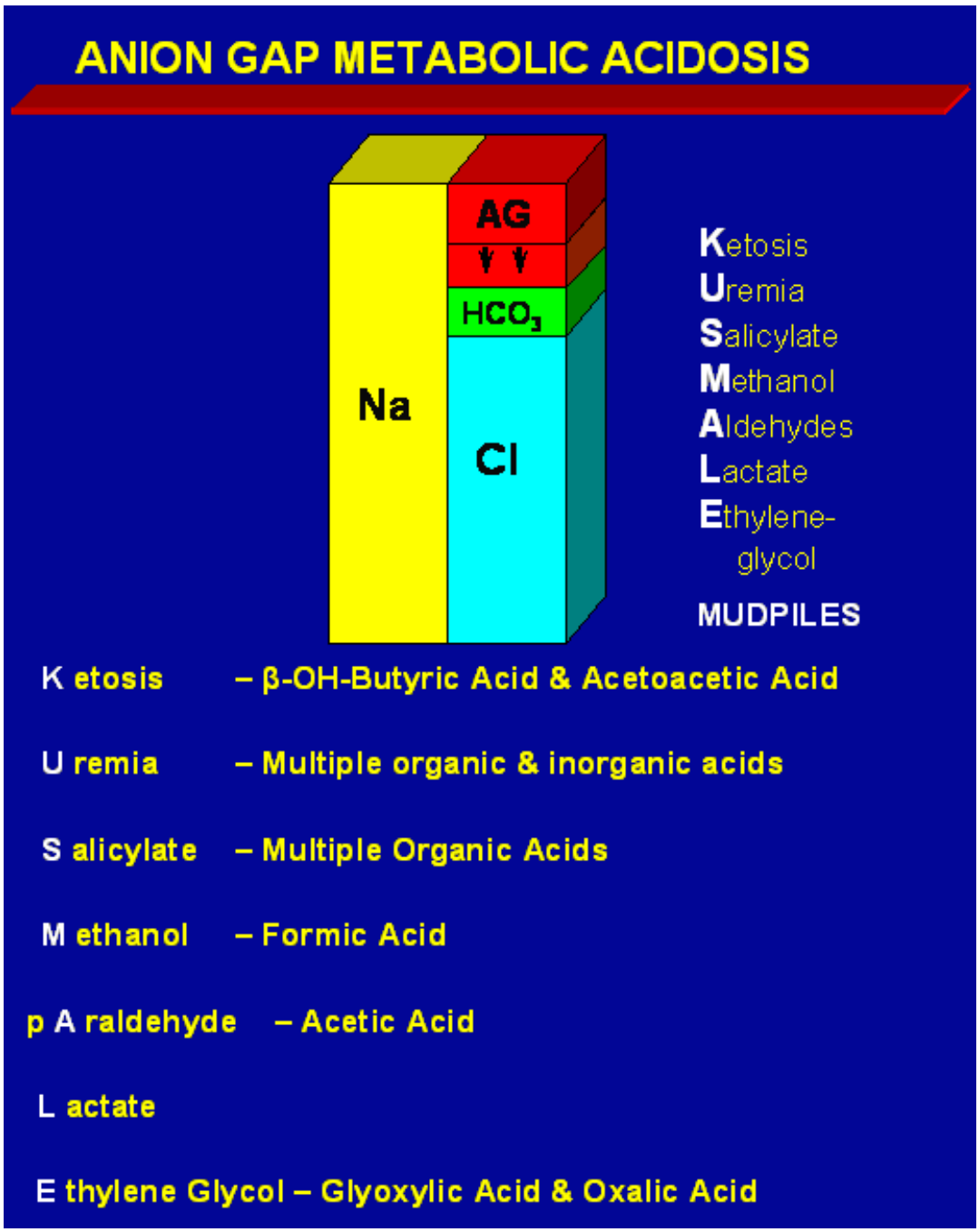
METABOLIC ACIDOSIS

- **Clinical Features:**
    a. Peripheral resistance ↓ SVR
    b. Myocardial contractility ↓
        - ↓ BP
        - pulm. odema
        - Hypoxia , vent. Fib.
    c. Kussmaul breathing
    d. Chronic Acidosis-.Bone changes - RTA - CRF

Major Causes of Metabolic Acidosis According to Mechanism and Anion Gap

Mechanism of acidosis	Increased AG	Normal AG
Increased acid production	Lactic acidosis Ketoacidosis Diabetes mellitus Starvation Alcohol-associated Ingestions Methanol Ethylene glycol Aspirin Toluene (if early)	
Loss of bicarbonate or bicarbonate precursors		Diarrhea or other intestinal losses (eg, tube drainage) Type 2 (proximal) RTA Posttreatment of ketoacidosis Toluene ingestion Carbonic anhydrase inhibitors Ureteral diversion (eg, ileal loop)
Decreased renal acid excretion	Chronic renal failure	Some cases of chronic renal failure Type 1 (distal) RTA Type 4 RTA (hypoaldosteronism)

- Anion Gap:
  - Should be calculated regardless of the Primary disturbance
  - In serum, the Sum of all anions & all cations must be **equal**
  - Negative charges on proteins account for the missing unmeasured anions
  - AG calculation reveals a hidden AGMA



- Metabolic Acidosis Rx:
  - Treat the underlying Cause
  - **Alkali Therapy ($NaHCO_3$) =** 1/3 wt(kg) x HCO_3deficit (24 - actual) = mmol/L
    - ✓ half of it to be given over the period of 12-24 hours
  - Dialysis

- Acidosis-treatment :

(Key difference in therapy of AGAP & Non-AGAP acidosis)

- For AGAP acidosis, you wouldn't use HCO_3 therapy until pH <7.2 or 7.1
- For Non-AGAP acidosis, the primary problem is insufficient HCO_3, not overproduction of acid, so you WOULD use HCO_3 therapy to correct serum HCO_3 to about 20.

METABOLIC ALKALOSIS

- Generated by:
  - **Loss of H ions by** GUT, Kidneys mineralocorticoid excess, Diuretics
  - **Addition of** HCO_3 , Citrate , Lactate , Acetate
- **Maintained by:**
  - **↑ $NaHCO_3$ reabsorb by kidney**
  - ECF Volume↓, Cl↓, K↓, mineralocorticoid ↑

Urine chloride most important:

a. **Volume depleted-NaCl responsive**

b. **Volume expanded- NaCl resistant**
   - Clinical Hx & physical exam
   - obviates the need of urinary chloride.

- **Chloride Resistant: (Urine Cl > 20) Volume Resist:**
  1. Primary Aldosteronism. } ↑ BP
  2. Cushing's syndrome } ↑ BP
  3. Licorice } ↑ BP
  4. Bartter's syndrome
  5. **Diuretics (recent)**

- **Chloride responsive (Urine Cl < 10 nmol/L) Volume- sensitive:**
  - Vomiting
  - gastric drainage
  - Diuretic therapy (remote)

- Clinical Features:
    - Muscle cramps and weakness (primary Aldo.)
    - Neuromuscular irritability
    - Tetany
    - ↑reflexes
    - PH 7.6 Cardiac Arrythmias

- Met. Alkalosis Rx

1. **NaCl infusion(Volume replacement)**
2. **K supplements**
3. Treat the **<u>Underlying Causes</u>: e.g.** Vomiting
4. Acetazolamide (in Vol resistant → HCO_3 excretion)
5. HCl ,NH_4 Cl (argenine Cl)
6. Hemodialysis (low HCO_3)
7. Removal of mineralocorticoid secreting tumors

RESPIRATORY ACIDOSIS ($\uparrow PCO_2$):

- CAUSES:
  - **CNS DEPRESSION:**
    SEDATIVES, RESPIRATORY CENTER LESIONS
  - **NEUROMUSCULAR DISORDERS:**
    MYOPATHY, NEUROPATHY
  - **THORACIC CAGE LIMITATION:**
    KYPHOSCOLIOSIS, INJURY, SCLERODERMA
  - **IMPAIRED LUNG MOTION:**
    PLEURAL EFFUSION, PNEUMOTHORAX
  - **Ac & Ch LUNG DISEASE:**
    COPD, PNEUMONIA, PULMONARY EDEMA, ACUTE OBSTRUCTION

- ACUTE SYMPTOMS:
  ANXIETY, DELIRIUM, SOMNOLENCE (CO_2 NARCOSIS)

- TREATMENT:
  of UNDERLYING DISORDER, VENTILATORYSUPPORT

RESP. ALKALOSIS ($\downarrow PCO_2$)

- CAUSES

1. HYPOXEMIA:

PULMONARY DISEASE, CHF, BP, HIGH ALTITUDE

2. PULMONARY DISEASE:

PNEUMONIA, EMBOLI, EDEMA

3. STIMULATION OF MEDULLARY RESPIRATORY CENTER:

SEPSIS, PSYCHOGENIC, HEPATIC FAILURE, SALICYLATE INTOXICATION, PREGNANCY(PROGESTERONE), NEUROLOGIC DISORDERS, POST-CORRECTION OF METABOLIC ACIDOSIS

4. MECHANICAL VENTILATION

- SYMPTOMS: LIGHTHEADEDNESS, PARESTHESIA, TETANY
- TREATMENT: of UNDERLYING DISORDER

EVALUATION:
Primary Disorder ?
Acidosis or Alkalosis

- Components of Acid Base Disorders:

Respiratory Disorders:

Breathe Too MUCH! → **Respiratory Alkalosis**

$$H^+ + HCO_3 \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$$

Breathe Too LESS! → **Respiratory Acidosis**

$$H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3 -$$

Metabolic Disorders:

Add Acid or Loose HCO3 → **Metabolic Acidosis**

Add Alkali or Loose Acid → **Metabolic Alkalosis**

If it is <u>Respiratory</u> then Renal [metabolic] compensation

If it is <u>Metabolic</u> then Respiratory compensation

BUT

Compensatory responses <u>will NOT bring the pH to normal</u>; but close <u>to</u> normal.

COMPENSATORY RESPONSES

Primary disorder	Adaptive response	Limits of Adaptation	Time of Adaptation
▸ M. Acidosis	$\Delta pCO^2 = 1.2 \times \Delta HCO^3$	pCO^2 not <10 mmHg	12 to 24 h
▸ M.Alkalosis	$\Delta pCO^2 = 0.7 \times \Delta HCO^3$	pCO2 not > 55 mmHg	to 36 h
▸ R.Acidosis			
acute	$\Delta HCO^3=0.1 \times \Delta pCO^2$	HCO3 not >30 mEq/L	Min to hrs
chronic	$\Delta HCO^3=0.4 \times \Delta pCO^2$	HCO3 not >45 mEq/L	Days
▸ R.Alkalosis			
acute	$\Delta HCO^3=0.2 \times \Delta pCO^2$	HCO3 not < 17 mEq/L	Min to hrs
chronic	$\Delta HCO^3=0.4 \times \Delta pCO^2$	HCO3 not < 12 mEq/L	Days

ACID BASE EVALUATION:

Basic things:

Clinical State

Clues to acid-base disorder :

CNS- coma.....	Resp.acidosis / R.alkalosis
seizures	Met. acidosis
CCF/ P.edema/cirrhosis...	Resp. Alkalosis
Sepsis / Shock.....	Met.Acid / Resp.alk
Resp.sys- tachypnea	R.Alkalosis
COPD, bradypnea	R. Acidosis
GIT- vomiting.....	M. Alkalosis
diarrhea/aspiration	M. Acidosis
Renal- failure.....	M. Acidosis
DKA.....	M.Acidosis
HTN / Diuretics use.....	M. alkalosis

(Basic Rules of the Game)

pH, CO_2, HCO_3, AG

1. **PH=7.4 CO_2 =40 HCO_3 =24**

2. **HCO_3 < 13 Definitely Metabolic Acidosis**

3. Anion Gap

Na= 139 Cl= 103 HCO_3=24

AG = [+VE] – [-VE]

AG = Na – [Cl+HCO_3]

= 139 – [103+ 24]

= 139 – 127

= 12

Charges on Ca, Mg, K balanced by SO_4 , PO_3,So not included in equation

AG >20 Definitely Metabolic Acidosis

AG 12-20 = MA Or MAlk

Causes of High AG MA:

M	Methanol	[Formic Acid]
U	Uremia	[Multiple organic & inorganic]
D	DKA	[Acetoacetate, β-OH Butyrate]
P	Paraldehyde	[acetic acid]
I	Isopropyl Alcohol	[Lactate]
L	Lactic Acidosis	[Lactate]
E	Ethylene Glycol	[Oxalate, Glycolate]
S	Salicylates	[Lactate & Ketoacids]

The Game (Examples):

(1)

15 y/o Type-I diabetic presented to ER with pneumonia, investigations as follows:

HCO_3= 11 Na= 144 Cl= 100 AG= 33

???

HCO_3< 12 So, Definitely MA

AG= 32 [>20] So, Definitely MA

pH=7.25, CO_2= 25,

Low CO_2 is the respiratory compensation

How ↓ should be CO_2 ?

Last 2 digits of pH 7.25 : CO_2 = 25

↓ PCO_2 = Δ HCO_3 x 1.2

= [24-12] x 1.2

=12 X 1.2 =14.4 OR 15

= 40 – 15 = **25**

HCO_3	PCO_2
24	40
12	**25**

Dx: High AG MA

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(2)

18 y/o asthmatic admitted with exacerbation

CO_2= 20

↓10 PCO_2 = 2 ↓ HCO_3 ,

Δ pCO2 x 0.2 = expected HCO3

PCO_2	HCO_3
40	24
30	22
20	20
Here 20	20

AG=10, pH= 7.48

Dx: Acute Respiratory alkalosis

5-10 minutes for Compensation Max: 17 meq/L

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(3)

30 y/o cirrhotic CO_2 = 20, HCO_3 =16, pH = 7.49 AG = 11

Expected HCO_3 = 20 [If this is Acute RAlk]

Here 16

Chronic Resp Alkalosis

↓10 PCO_2 = 4 ↓ HCO_3

Δ pCO_2 x 0.4 = expected HCO_3

20 x 0.4 = 8

PCO2	HCO3
40	24
30	20
20	16

2-3 Days for Metabolic Compensation Max: 14 meq/L

(4)

60 y/o patient with h/o COPD exacerbation for 2 days

CO2= 60 HCO_3 = 26 AG= 10 pH= 7.33

Acute Respiratory Acidosis

↑10 PCO_2 = ↑ by 1 HCO_3^-

$\Delta pCO2 \times 0.1 = \Delta HCO3$

PCO_2	HCO_3^-
40	**24**
50	**25**
60	**26**

In our Pt 60 26

5-10 minutes for Compensation Max: 30 meq/L

(5)

16 yr male ate fast food, had diarrhea for 2 days

HCO_3 = 8, AG = 10, Cl = 114

PCO_2 ↓ = 20

$\Delta CO_2 = \Delta HCO_3 \times 1.2$,

$= 24 - 8 \times 1.2 = 16 \times 1.2 = 19.2 = 20$

$CO_2 = 40 - 20 = 20$ Pt's $pCO_2 = 20$

Nml AG MA = Hyperchloremic NAGMA

Causes of Hyperchloremia in Acid base Disorders:

Hyper Cl NAGMA, Respiratory alkalosis, Dehydration

- Urine Anion Gap:

Helps **for D/D of Non-AGMA**

Urine electrolytes: Na, K, Cl, HCO3, NH4

Urine AG= [Na+K] – Cl = is a Negative value

represents **NH_4 secretion** as it cannot be measured

- UAG in NAGMA
  - **Diarrhoea** :
    - » NH_4 excretion is N
    - » UAG = negative
  - **Renal Tubular Acidosis I & IV** :
    - » NH4 excretion is ↓
    - » UAG = positive

Now More Complex things!
But they are EASY!
IF U FOLLOW THE RULES!

Clinical Picture: AG HCO_3 PCO_2 pH

In the presence of NORMAL pH, If abnormal CO_2 or HCO_3
IT IS A MIXED Disorder!
At least 2 primary disorders

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23 y/o female with septic shock due to bilateral pneumonia

Na=140, Cl=102, HCO_3=15
AG = 23 [HAGMA]
CO_2 = 45
↑ CO_2 [RA]
pH= 7.10

Primary HAGMA & Primary RA

---

60 y/o female with CHF, shock, restless, ↑ RR, BP unrecordable, chest rales and no peripheral edema

Na=139, Cl=95, HCO_3=16, AG= 28

HAGMA

CO_2 = 25
↓CO_2 = ΔHCO_3 X 1.2
8 X 1.2 = 9.6
So CO_2 should be 30
Here CO_2 is 25!

Something brought it ↓ further : R ALK

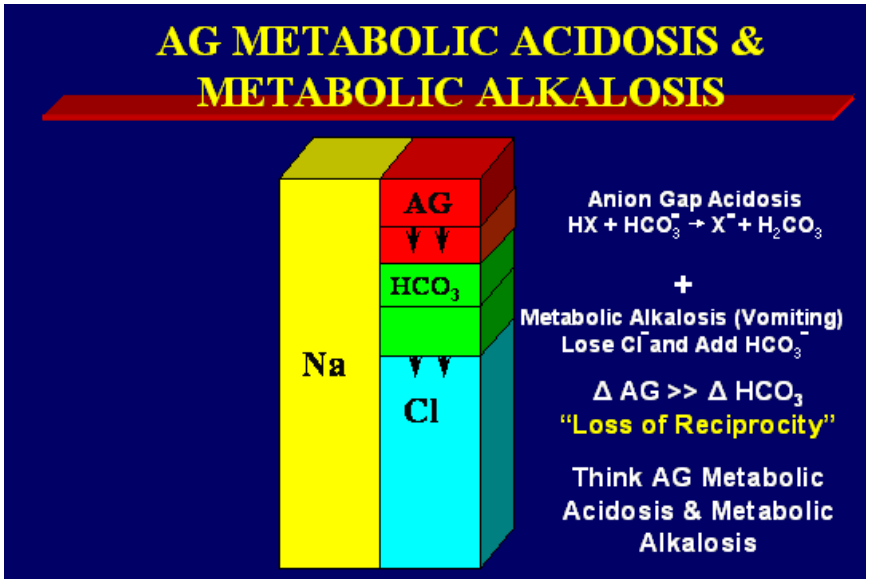
So Far we AGREE : R ALK and HAGMA

	↑AG : ↓ HCO_3
Here	**16 : 8**
	2 : 1

So ⇒ Something is keeping the HCO_3↑ ⇒ MAlk

Dx: HAGMA + RAlk + MAlk

PH= 7.43



- Steps in judging if it is simple or mixed:

- Determine the **major/primary** disturbance
- Check **directions** from normal of changes in buffer pair

In all **simple** dis, HCO_3 & pCO_2 change in **same** directions.

If they change in **OPPOSITE** directions (up-down or down-up) , the disorder must be **MIXED**

- Check if **compensation** is appropriate

Do You remember HENDERSON HASSELBALCH equations?

If you Saied NO, try to remember them NOW.

Respiratory acidosis $pH \downarrow \propto \frac{HCO3 \uparrow *}{PCO2 \uparrow}$	Respiratory alkalosis $pH \uparrow \propto \frac{HCO3 \downarrow *}{PCO2 \downarrow}$
Metabolic acidosis $pH \downarrow \propto \frac{HCO3 \downarrow}{PCO2 \downarrow *}$	Metabolic alkalosis $pH \uparrow \propto \frac{HCO3 \uparrow}{PCO2 \uparrow *}$

* - compensation process

APPROACH TO ACID-BASE SOLVING

1. What is the **Primary** disturbance ?
2. Is **Compensation** appropriate ?
3. What is the **Anion Gap** ?
4. What is **delta – delta** value ?
5. Does the change in AG equals change in HCO_3

- Gap of the Gaps:

- Change in AG equals change in HCO_3, ie Reciprocal change.

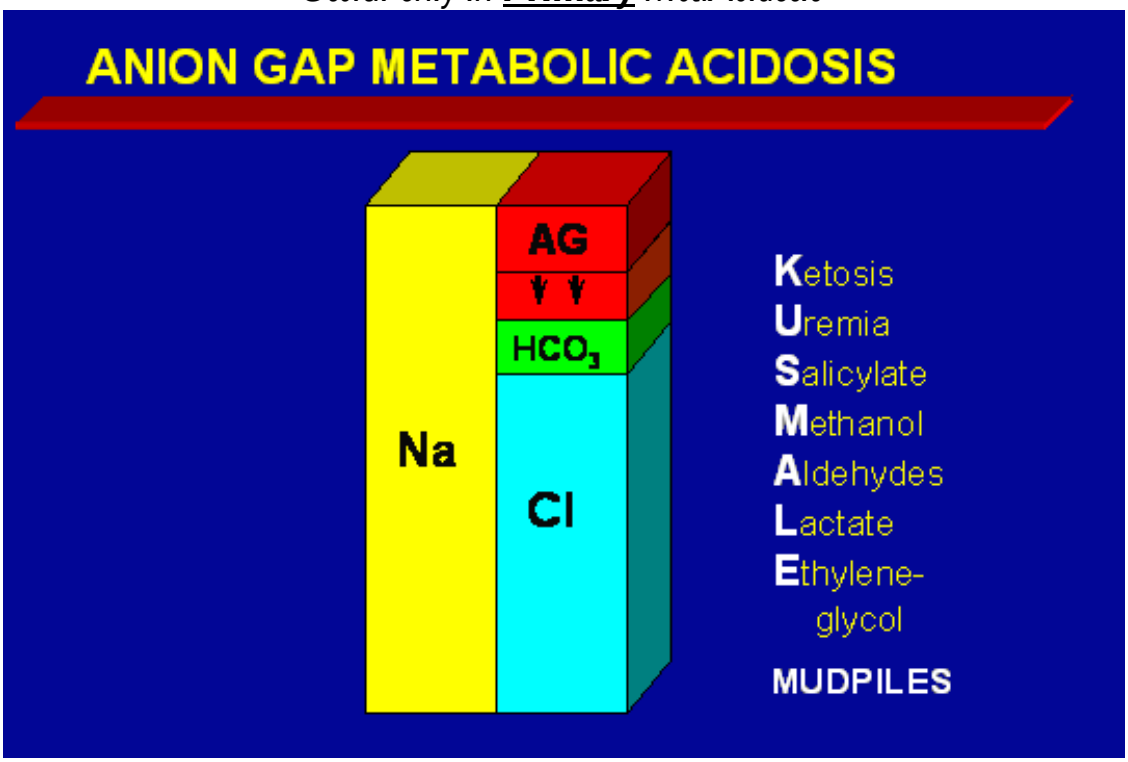
Delta/Delta ratio (ΔAG : Δ **HCO3**)

(Δ AG / Δ HCO3)

If <1 = concurrent non-AGMA

If >2 = concurrent M.alkalosis

*Useful only in **Primary** Met.Acidosis*



Exam 1

47 yrs man , 3 d of diarrhea. o/e postural drop, :

Na	130	pH	7.24
K	3.2	pCO^2	23
Cl	100	HCO^3	10

pH ? Low = acidosis

HCO3 ↓ , so M.Acid

pCO2 ↓ , so cant be the primary disturbance

AG 130- {100+10} = 20 ↑ HAGMA

<u>Delta/Delta ratio (ΔAG ▪ Δ HCO3)</u>

20- 12 / 24-10 = 8/14 = <1

<1 = *concurrent non-AGMA*

Ex : 2

36 yrs lady in ER b/c general weakness

Na	130	pH	7.49
K	3.0	HCO3	35
Cl	85	pCO2	48

Primary? Alkalosis - Metabolic

Compensation ? is OK

Δ PCO2 = 35-24=11

=11× 0.7= 8

Expected PCO2= 40+8 = 48 is OK

AG? 130 – (85+30) = 15

small (1-5) increase in AG is common

D/D ? Useful only in Primary M.Acidosis

Ex 3

38 yr man with Diabetes , 4 days vomiting,

temp 39, BP 98/56

pH	7.5	Na	138
pCO2	42	K	3.0
HCO3	34	Cl	80

Gluc 28

Primary? M. alkalosis

Compensation? No , expected pCO^2 47

pt PCO2 is 42, so concomitant R.Alk b/c of infection

AG? 24 , so HAGMA from DKA or LA

D/D ? Not needed, only in Primary MA

ANS: M.alk + R. alk + HAGMA

.: The End :.

Done By : Nephro Team

If there is any comments, Please contact us on:

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